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CLEAN-ROOM FACILITIES FOR EXPLORER XXXV SPACECRAFT

by Francis N. LeDoux

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Greenbelt, Md.

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ABSTRACT

Costly delays and failures in past spacecraft projects have been attributed to the inadequacy or lack of contamination control. Currently, NASA requires that automated spacecraft with mission in the near vicinity of the moon be biologically decontaminated to a level of no more than 2.59×10^6 viable spore forms at time of launch. To reduce particulate and biological contamination of Explorer XXXV, various classes of clean rooms were used. Debris-generating operations were performed in uncontrolled areas with protection for flight hardware in the near vicinity. Decontamination, conformal coating, and encapsulation of electronics were performed in a class 10,000 conventional clean room; spacecraft buildup and some engineering tests were conducted in a class 100,000 conventional clean room. Electronic systems field checkout, cleaning and decontamination of small hand tools, instrument assembly, and/or functional operation tests, final spacecraft decontamination and assembly, and bioassaying were conducted in a class 100 bio-clean room environment. All clean-room areas were restricted in number of personnel, clean-room dress, deportment, and procedures. On the basis of the biorecords, it was determined that the Explorer XXXV surfaces contained not more than 9×10^5 microorganisms before decontamination. This low level has been attributed to the various clean-room environments and contamination controls utilized during assembly and/or testing.

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INTRODUCTION

Many spacecraft components are manufactured in various locales and shipped to Goddard Space Flight Center (GSFC) for use in a spacecraft system. The delay between the inspection of components after manufacturing and the time the component is in the process of assembly or mechanical integration is a major factor in component reliability. During these intervals the probability is highest that satellite components, subassemblies, and assemblies will be damaged or made less reliable. Each day that a satellite component, satellite, or space probe is exposed to unfavorable conditions such as particulate and biological contamination increases the probability of harm or degradation.

Particulate contamination is extremely important since costly delays and failures in past spacecraft projects have been attributed to the inadequacy or lack of contamination control. Biological contamination of lunar and planetary spacecraft and/or their components is of considerable concern to the NASA Headquarters Office of Planetary Quarantine, which requires that automated spacecraft with a mission near the moon be decontaminated to a level of not more than 2.59×10^6 viable spore forms on board at time of launch. These particulate and biological cleanliness requirements, necessitated controlled facilities that would allow various levels of clean environments in which to perform specific tasks on the Explorer XXXV spacecraft at Goddard Space Flight Center and in the field during the launch checkout.

This paper describes the environments and physical features of the GSFC facilities used in the Explorer XXXV decontamination during structural buildup, mechanical integration, assembly, and biological sampling of hardware and spacecraft. This paper also indicates the control and environments to which the spacecraft was subjected in the field and the results of biological decontamination of the spacecraft (presently in lunar orbit), which was launched 19 July 1967 from Cape Kennedy, Florida.

ASEPSIS CONTROL DURING ASSEMBLY

Spacecraft Preparation Area

The debris-generating operations performed on a component or the spacecraft structure were conducted in the Spacecraft Preparation Area. This area is 25- by 20-feet and contains drill presses, filing machine, punch press, and sundry power hand tools. When it was required to custom-fit a component to a structure and the operations of filing, drilling, or scraping of metal were necessary,

Figure 1—Spacecraft preparation area.

a shield was built to protect other components from falling metallic particles. In addition, a vacuum cleaner was used to gather loose chips as they were generated. The vacuum cleaner inlet nozzle was placed in the immediate work area. Before a spacecraft or a component was removed from this area, it was vacuum cleaned and wiped with an alcohol-dampened, cotton cloth. Figure 1 shows such an operation being performed. The spacecraft then was transported on its dolly to the Hi-Bay Clean-Room Complex where assembly, integration of components, decontamination, and engineering tests were conducted.

Hi-Bay Clean-Room Complex

The Hi-Bay Clean-Room Complex (Figure 2) consists of a 100,000 class, conventional clean-room, approximately 70 feet square and 24 feet high. Within this clean-room are class 100, portable,

Figure 2—Hi-bay clean-room complex.

vertical laminar flow units, expandable in multiples of 4- by 8-foot units, and class 100 horizontal-flow benches. The vertical flow units housed the spacecraft in the class 100,000 area when no work was being done on it. The spacecraft was always precleaned before being placed under the down-flow units; cleaning consisted of wiping and vacuum cleaning the surfaces. The down-flow units were also used to perform instrument integration, decontamination, and bio-sampling of components. The flow benches were used to assemble delicate mechanisms and to clean them at each stage of assembly. After the spacecraft was mechanically integrated, it left the clean-room area for electronic integration and/or systems environmental tests. At that time, the spacecraft was protected by a strippable coating, which was applied only to the exterior exposed surfaces.

Figure 3 shows in more detail one of the class 100, vertical down-flow units. The unit in the right foreground was used by the lead technician to perform a decontamination operation on the spacecraft. It was also used to store spacecraft not being worked on, to take bio-samples, and to prepare sterile media.

The electronic circuit modules, electrical connectors, and wiring harnesses to be cleaned, decontaminated, conformal-coated, and/or encapsulated were first precleaned with an aerosol of ethyl alcohol to remove deposits of solder flux and residual water lacquer remaining after fabrication. They were then injected into the class 10,000 area of the Bio-Clean-Room Complex.

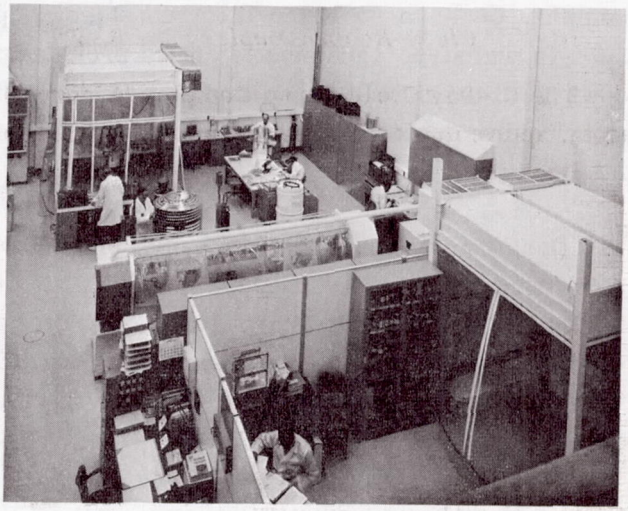

Figure 3—View of down-flow unit in the hi-bay clean-room complex.

Bio-Clean-Room Complex

Tests conducted by GSFC have indicated that particulate contamination in all areas of the complex is well below permissible NASA levels. The facility consists of four separate rooms with a total area of 600 square feet (Figure 4). Room A is a personnel preparation room with a brush vacuum mat at the entrance of the door to clean shoe bottoms. A closet with sterile clothing and a surgical wash basin are included. Room B, a small anteroom, is an airlock with a built-in air shower. The air shower has a 40-mph wind that lasts for 25 seconds and removes lint and skin scales from the skin and clothing of personnel. Room C is a work area containing decontaminating and

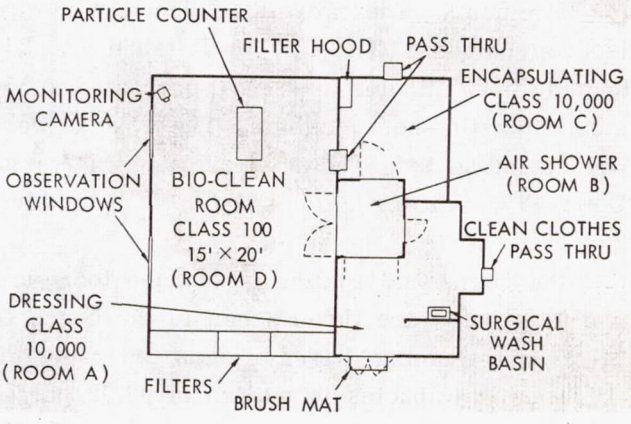

Figure 4—Bio-clean-room complex.

monitoring equipment, a positive-pressure air system, and an interlocking system on the doors that allows only one door to open at a time. This arrangement prevents the pressurized air system from being overridden.

Room D is a bio-clean room where satellites are decontaminated. An unusual feature of this room is a monitoring camera, which photographs the satellite and personnel every 5 seconds. This feature was included to check on faulty operations that may occur. Horizontal, laminar-flow air emanates from a 14-foot wall via modules with Cambridge high efficiency particulate air (HEPA) filter units. Filtration tests confirmed a rating for this room of between 0 and 66 particles of 0.5 micron and larger, per cubic foot of air. Walls are of prefabricated panels with 4-inch plastic foam insulation. Epoxy-coated steel forms the interior surfaces. A completely lighted ceiling gives shadowless, 200-foot-candle illumination at working levels. There are a minimum of 20 air changes per hour at a controlled temperature range of 67°F to 77°F, and a relative humidity of 40 to 45 percent. A constant temperature of 72°F is maintained, and a central, built-in wall-type vacuum system is provided in all four rooms, along with observation windows that are double-paned and sealed. Also included are pass-through chambers containing interlocking doors to ensure maintenance of a positive air-pressure when parts are brought into the room.

During any operation in a clean-room environment where a component is handled or a test is being performed on the spacecraft, it is highly probable that particulate and biological contamination will be released and transferred. In order to minimize the release or transfer of this contamination, it was deemed necessary that a procedure (Appendix A) be followed by personnel working in a clean-room area.

Clean-Room Assembly Tools

Tools used in the clean room were first precleaned by wiping off gross contamination with cotton wipers. The tools were then placed in a wire mesh basket and exposed to Freon TF vapor for 25 minutes. They were then placed in an ultrasonic bath containing a 50-percent solution of isopropyl alcohol (C_3H_7OH) for 25 minutes at 25 kHz. After removal from the solution, they were heated for 25 minutes in an oven preheated to 55°C. All tools were then packaged and sealed in sterile plastic sheet material. These packs were again packaged so that the tools would be double-packed and sealed. The outer package was removed just before injecting tools into the Goddard Down-Flow Unit for use in spacecraft assembly.

Packaging and sealing of cleaned tools are performed in a "white bench" (Figures 5, 6, and 7). There are three areas in the bench enclosure that are ultra-clean working areas; ultrasonic cleaning, assembly and/or inspection, and clean storage. This environment, having filtration efficiencies in excess of 99.95 percent and with particles as small as 0.3 micron, meets class 100. It is temperature and humidity controlled and maintains a positive pressure in each working area.

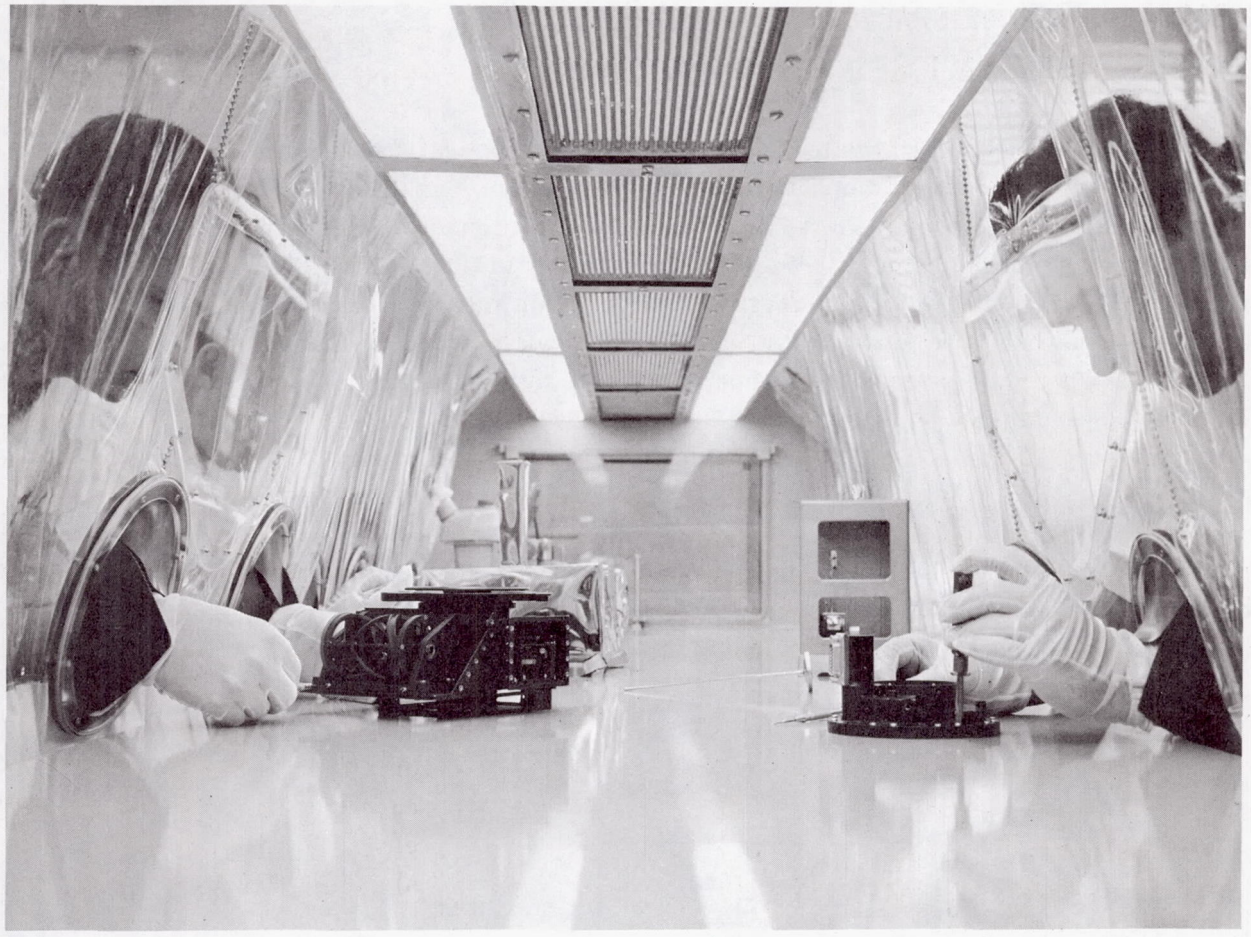

Figure 5—White bench, assembly operation.

Figure 6—Technician inserting cleaned tool into plastic envelope.

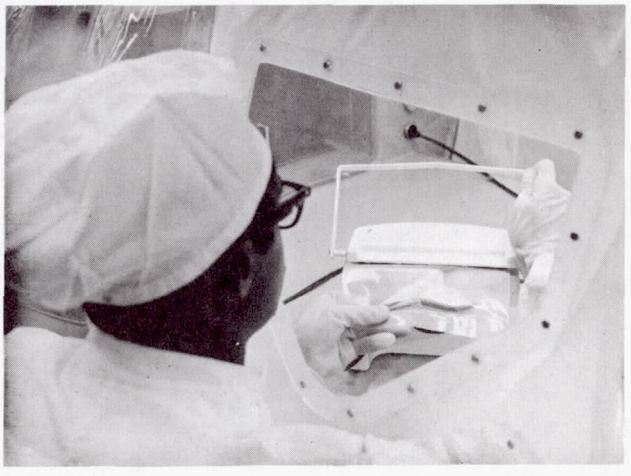

Figure 7—Technician sealing plastic envelope containing tool.

ASEPSIS CONTROL OF SPACECRAFT DURING CONDUCTANCE OF FIELD TESTS, CAPE KENNEDY, FLORIDA

The NASA Planetary Quarantine Officer requires that potential lunar-landing spacecraft be handled, tested, and prepared for launch over a period of not less than T-20 days in spaces conforming to the NASA Laminar-Flow Clean-Room Specifications, which state that spaces shall be of the laminar-flow type, with air movement from ceiling to floor, and shall conform to Federal Specifications 209, class 100 clean-room standards. This requirement could not be met completely since spacecraft had to be in two test areas that could not be made to conform to clean-room specifications. When the spacecraft was undergoing tests in these areas, it was protected from particulate and bio-contamination by a sterilized asepsis covering.

Cape Kennedy Clean-Room Facility

The facility at Cape Kennedy (Figure 8) was a class 10,000 clean-room complex consisting of both horizontal laminar flow and conventional areas. The Goddard class 100 laminar down-flow unit was placed in the laminar flow clean-room 10 feet from the face of the final filtered air inlet.

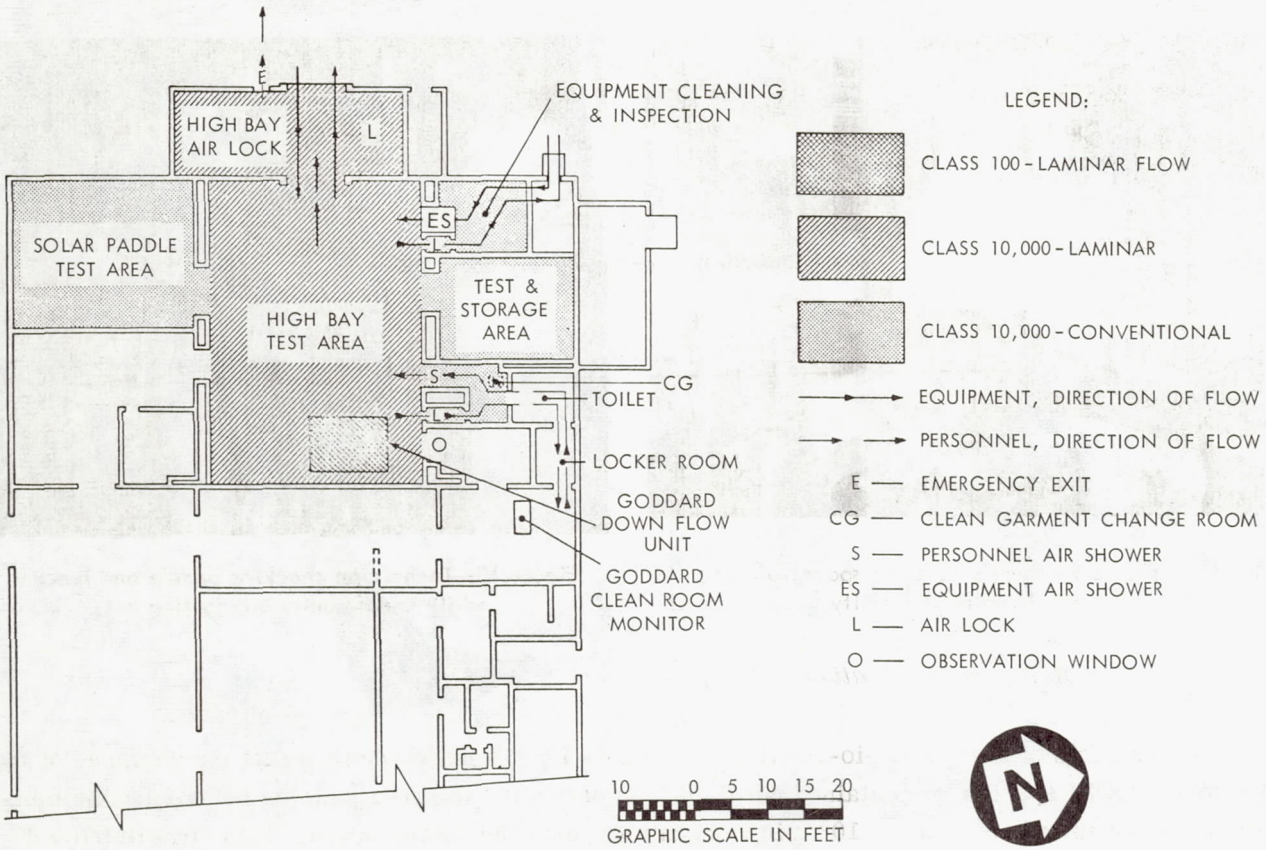

Figure 8—Spacecraft clean-rooms, Building "AE," KSC.

The electronic checkout of all flight instrumentation and experiments was conducted while the spacecraft was in the class 100 environment. Personnel conducting the tests were limited to a maximum of five at one time in the class 10,000 area and no more than two of these at any one time in the Goddard down-flow unit. The personnel conducting experiment tests in these areas were subjected to restrictions of clean-room deportment and dress.

Gantry Air Cooling-Hat Shroud

After the completion of tests in the Spin Balance Facility, an asepsis cover previously sterilized with ethylene oxide was placed over the entire spacecraft (Figure 9). The spacecraft was canned, and the container was pressurized with a slightly positive pressure of dry, gaseous nitrogen and delivered to the launch gantry. The transfer container was removed, and the asepsis bag allowed to remain intact over the spacecraft until the air-cooling-hat shroud (Figure 10) was placed in operation. The air into the cooling hat shroud met class 100 requirements; it was temperature-controlled and passed through a diffuser designed to simulate a vertical laminar flow of filtered air over the spacecraft. The spacecraft was in this environment until separation of the service umbilical at lift-off. The removal of the protective strip coating, final decontamination, and sample-taking for bio-assays were performed on the spacecraft while it was in the cooling-hat shroud.

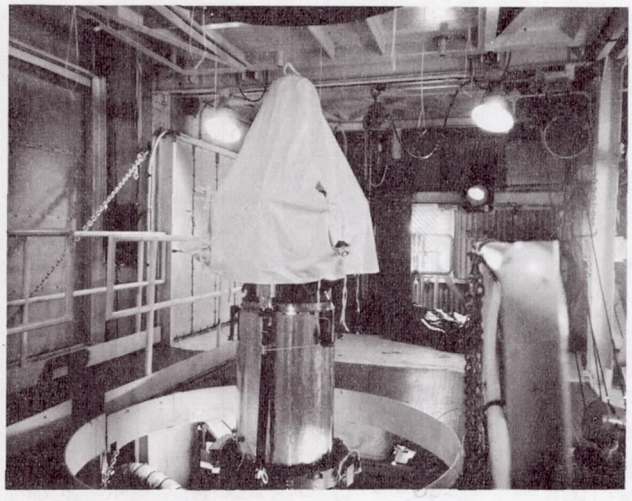

Figure 9—Asepsis cover on spacecraft at spin balance facility.

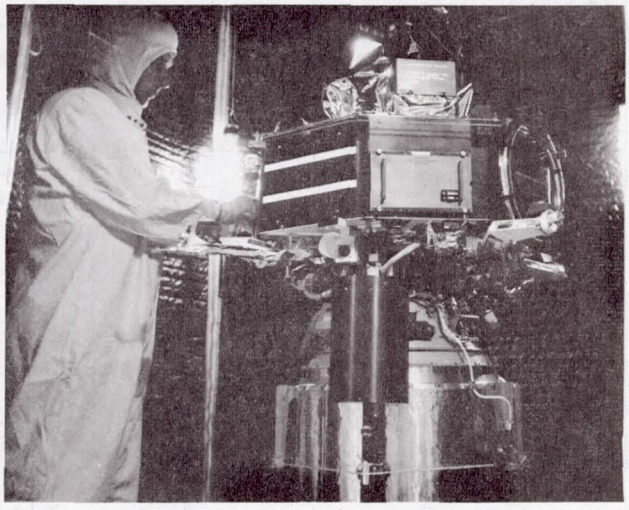

Figure 10—Technician checking paddle arm bracket while under gantry air-cooling hat.

Results of Bio-Decontamination

On the basis of the GSFC bio-records (see Table 1), it was determined that the surfaces of the Explorer XXXV spacecraft contained not in excess of 9×10^5 microorganisms before decontamination and not in excess of 2.7×10^4 microorganisms after decontamination. This constituted a 97 percent reduction. The estimate of viable organisms contained within components (Table 2) was based on past history and known manufacturing environments. It was determined that, of the total

Table 1

Compilation of Viable Organisms on Surfaces.

Area Class	Total Area (in^2)	Counts of Viable Organisms on Surfaces							
		Contaminated				Decontaminated			
		Aerobic		Anaerobic		Aerobic		Anaerobic	
		Veg.	Spores	Veg.	Spores	Veg.	Spores	Veg.	Spores
Occluded "A": Electronic modules	8759	212899	62232	26858	25547	5937	3251	4099	55
Occluded "B": Surfaces that module frames occlude	1138	4033	0	5914	0	72	0	3450	0
Occluded "C": exterior of module frames	5813	56300	4489	9923	85	20	2030	192	0
Occluded "C": Other interior exposed surfaces of the spacecraft that the cover occludes	5195	20001	17467	898	40206	79	178	0	369
Interior surfaces "D": Other interior surfaces of the spacecraft —1 Body —2 Motor —3 Assembly occluded	8490	63174	6517	8747	1750	1985	502	38	12
Exterior surfaces "E": Exterior surfaces of the spacecraft —1 Body —2 Motor —3 Assembly occluded	71437	228329	80818	19321	4344	3671	420	281	545
Final totals of contamination of the AIMP-E spacecraft	Total 700.2 sq. ft.	584736	171523	71661	71932	11764	6381	8060	981
Totals		9×10^5				2.7×10^4			

Table 2

Compilation of Viable Organisms Contained Within Components.

Components	Estimated Range	Number of Components	Accumulative Total $\times 10^3$	
			Low	High
Resistors	0-1	11612	0	11.6
Capacitors	10-100	3153	31.5	326.9
Diodes	0-1	4005	31.5	330.9
Transistors	0-1	3164	31.5	334.1
Relays	100-1000	15	33.0	349.1
Crystals	0-1	1	33.0	349.1
Inductors	0 < 100	148	33.0	363.0
Toroid transformers	0 < 100	117	33.0	375.6
Batteries	0	0	33.0	375.6
Metals	0	0	33.0	375.6
Tubes	0	4	33.0	375.6
Explosives	10	8	33.1	375.7
Foam	1/ml	14727 ml	47.8	390.4
Nylon-Dacron	0	876		
Teflon insulation	0	16		
Magnetic cores	0	0		
MOSFETS	0	747		
Potentiometers	?	17		
Flat paks	0	551		
Fuses	0	15		
Thermistors	0	35		
Estimated total - internal burden			47.8	390.4
Average internal burden			219.0	

viable life remaining in the components (Table 3), 10 percent would be spore forms. Of this 10 percent, approximately two-thirds would be aerobic, and the remainder anaerobic.

As a result of the overall evaluation (Table 4) it was determined that at time of launch, the Explorer XXXV spacecraft contained not over 2.5×10^5 organisms. Of these, an estimated 2.2×10^5 organisms were contained inside the components and foam encapsulant and 2.7×10^4 organisms on the surfaces; 7.4×10^3 of those on the surface were spores.

Table 3

Estimated Spore Loading at Launch and Lunar Impact.

Area	Aerobic	Anaerobic	Totals
Surfaces	1.3×10^4	1.9×10^3	1.5×10^4
Internal burden	1.5×10^4	7.3×10^3	2.2×10^4
Grand totals	2.8×10^4	9.2×10^3	3.7×10^4
Remaining at lunar impact	1.89×10^{-9}		2.2×10^4

Table 4

Spacecraft Microbial Load at Launch.

Type Load	Contamination Level
Internal burden	2.2×10^5
Surfaces	2.7×10^4
Total load	2.5×10^5

The Explorer XXXV spacecraft achieved a successful orbit with a life expectancy of 3 years and will have 1440 cycles of temperature change between -45°C and +50°C in an ultra-high vacuum. Under this environment, the spore population on the exposed surfaces of the spacecraft should be reduced to 1.89×10^{-9} at time of lunar impact, and all vegetative life is assumed to exist no longer; only the internal spores (2.2×10^4) would remain.

The Planetary Quarantine Officer recommended certification of the Explorer XXXV spacecraft based on the evaluation of records maintained at the Goddard Space Flight Center, visual observations of control procedures, and assessment of the microbial environment of the spacecraft while in residence at the Eastern Test Range.

SUMMARY

Debris-generating operations are performed in an uncontrolled area. Protection is given flight hardware in the near vicinity of the debris-generating operation.

Decontamination, conformal-coating, and encapsulation of electronics are performed in a class 10,000 clean-room. The area is restricted to numbers of personnel, clean-room dress, deportment, and procedure.

Spacecraft build-up and some engineering tests are performed in class 100,000 clean-room. The area is restricted to clean-room dress and deportment.

Instrument, hardware, and spacecraft decontamination; assembly; experiment integration; bio-sampling; and bio-assays are performed in a class 100 environment. The areas are restricted to number of personnel, clean-room dress, deportment, and procedures.

Decontaminated instrument assembly and/or functional operation tests are conducted on class 100 horizontal laminar flow benches.

Small hand tools are cleaned and decontaminated, packaged, and sealed to retain level of cleanliness while in a class 100 white bench environment.

Prior to shipment to launch complex, the spacecraft is dissassembled and precleaned in a class 10,000 clean room. Spacecraft interior final cleaning decontamination, bio-sampling, and reassembly is performed in a class 100 bio-clean room. The area is restricted to number of personnel, specific clean-room dress, and clean-room deportment.

An electronic systems checkout is performed in the field while the spacecraft is housed in a class 100 clean-room environment or while protected by an asepsis covering.

Final checkout, decontamination, and bio-sampling are conducted in a class 100 environment in a laminar down-flow cooling-hat shroud on the gantry. The spacecraft is bathed with class 100 filtered and temperature-conditioned air until separation of service umbilical at lift-off.

Goddard Space Flight Center
National Aeronautics and Space Administration
Greenbelt, Maryland, February 6, 1968
039-01-01-01-51

Appendix A

Clean-Room Regulations

General Clean-Room Deportment

Personnel in any of the clean room areas observed the following clean-room regulations and adjusted accordingly.

1. Individuals having respiratory or skin ailments are not allowed to work in the clean-room areas.
2. Individuals with colds or severe sunburn are not permitted to work in clean-room areas.
3. No unauthorized personnel are allowed in clean rooms.
4. Only test fixtures, tools, jigs, and assembly fixtures needed to perform the required task are permitted in clean rooms.
5. No abrasives such as files, crocus cloth, etc., are permitted.
6. No shredding or masking tapes are permitted.
7. Exposed parts or components are not to be left on work benches.
8. Only approved clean-room garments will be worn in the various clean-room areas.
9. No smoking or eating is allowed in clean rooms.
10. No person having cosmetics such as after-shaving talc, lip ice, etc., or external medication is allowed in clean room.
11. No pencils are allowed in clean room areas. Ball point pens and lint-free paper are permitted.
12. No horse-play will be tolerated; movements are to be slow and rhythmic.
13. No watches or jewelry are to be worn in the clean-room areas.
14. Scratching the head, eyebrows, or exposed skin areas is taboo.
15. Coveralls are not to be unzipped when in the clean room areas.
16. No skin areas are to be exposed between gloved hand and coveralls.
17. Emergency exits will be used only in legitimate emergencies.
18. No equipment will be allowed in the clean-room areas that has not been first precleaned.
19. No more than two personnel will be allowed to work at one time under the Goddard Down-Flow Unit.
20. Project and custodial personnel are not to disturb, or be in the near vicinity of, any clean-room monitoring equipment.

Clean-Room Garments Required

Spacecraft Preparation Area

1. None; street clothes are adequate

Hi-Bay Clean-Room Complex

1. Class 100,000 area: shoe covers, cotton gloves, and smocks
2. Class 100 areas: shoe covers, cotton or surgical-type gloves (depending upon operation), smocks, hats, and in addition face masks are required during decontamination and/or bio-sampling operation while under the vertical down flow unit.

Bio-Clean-Room Complex

1. Class 10,000 area: coveralls, shoe covers, cap, sterile gloves (surgical-type)
2. Class 100 bio-area: shoe covers, coveralls, cap, hood, sterile rubber gloves (surgical-type), and face mask

Gantry Cooling-Hat Shroud

1. Class 100 area: shoe covers, velostate boots, leg stats, sterile rubber gloves (surgical-type), fire-proofed cap, hood, and coveralls
2. In addition face masks are required during removal of strip-coating, final decontamination, and bio-sampling.

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